

Date: 8/1/96

Technical Standard Order

Subject: TSO-C117a, AIRBORNE WINDSHEAR WARNING AND ESCAPE GUIDANCE SYSTEMS FOR TRANSPORT AIRPLANES

a. Purpose and Scope.

(1) Introduction. This Technical Standard Order (TSO) prescribes the minimum performance standards for airborne windshear warning and escape guidance systems for transport category airplanes. This document defines performance, functions, and features for systems providing windshear warning and escape guidance commands based upon sensing the airplane's encounter of such phenomena. It is not applicable to systems that look ahead to sense windshear conditions before the phenomenon is encountered nor to systems that use atmospheric and/or other data to predict the likelihood of a windshear alert. Airborne windshear warning and escape guidance systems that are to be identified with TSO identification and that are manufactured on or after the date of this TSO must meet the minimum performance standard specified herein.

(2) Scope. This TSO applies only to windshear warning systems which identify windshear phenomenon by sensing the encounter of conditions exceeding the threshold values contained in this TSO. In addition to windshear warning criteria, this TSO provides criteria applicable to systems that provide optional windshear caution alert capability. Windshear escape guidance is provided to assist the pilot in obtaining the desired flight path during such an encounter.

(3) Applicable Documents. The following documents shall form a part of this TSO to the extent specified herein. Should conflicting requirements exist, the contents of this TSO shall be followed.

(i) RTCA Document No. DO-160B, "Environmental Conditions and Test Procedures for Airborne Equipment," dated July 1984.

(ii) RTCA Document No. DO-178B, "Software Considerations in Airborne Systems and Equipment Certification," dated December 1992.

(iii) Society of Automotive Engineers, Inc. (SAE) Aerospace Recommended Practice (ARP) 4102/11, "Airborne Windshear Systems," dated July 1988.

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(4) Definitions of Terms.

(i) Airborne Windshear Warning System. A device or system which uses various sensor inputs to identify the presence of windshear once the phenomena is encountered and provides the pilot with timely warning. The system may include both windshear warning and windshear caution alerts. A warning device of this type does not provide escape guidance information to the pilot to satisfy the criteria for warning and flight guidance systems.

(ii) Airborne Windshear Warning and Escape Guidance System. A device or system which uses various sensor inputs to identify the presence of windshear once the phenomenon is encountered and provides the pilot with timely warning and adequate flight guidance to improve the probability of recovery from the windshear encounter. This system may include both windshear warning and windshear caution alerts.

(iii) Airborne Windshear Auto Recovery System. A device or system which integrates or couples autopilot and/or autothrottle systems of the aircraft with an airborne windshear flight guidance system.

(iv) Airborne Windshear Escape Guidance System. A system which provides the crew with flight guidance information to improve the recovery probability once encountering a windshear phenomenon.

(v) Failure. The inability of a system, subsystem, unit, or part to perform within previously specified limits.

(vi) False Warning or Caution. A warning or caution which occurs when the design windshear warning or caution threshold of the system is not exceeded.

(vii) Nuisance Warning or Caution. A warning or caution which occurs when a phenomenon is encountered, such as turbulence, which does not, in fact, endanger the aircraft because of the duration of subsequent change of the windshear magnitude.

(viii) Recovery Procedure. A vertical flight path control technique used to maximize recovery potential from an inadvertent encounter with windshear.

(ix) Severe Windshear. A windshear of such intensity and duration which would exceed the performance capability of a particular aircraft type, and likely cause inadvertent loss of control or ground contact if the pilot did not have information available from an airborne windshear warning and escape guidance system which meets the criteria of this TSO.

(x) Windshear Caution Alert. An alert triggered by increasing performance conditions which is set at a windshear level requiring immediate crew awareness and likely subsequent corrective action.

(xi) Windshear Warning Alert. An alert triggered by decreasing performance conditions which is set at a windshear level requiring immediate corrective action by the pilot.

b. General Standards. The following general requirements shall be met by all windshear warning and escape guidance systems:

(1) Airworthiness. Design and manufacture of the airborne equipment must provide for installation so as not to impair the airworthiness of the aircraft. Material shall be of a quality which experience and/or tests have demonstrated to be suitable and dependable for use in aircraft systems. Workmanship shall be consistent with high quality aircraft electromechanical and electronic component manufacturing practices.

(2) General Performance. The equipment must perform its intended function, as defined by the manufacturer.

(3) Fire Resistance. Except for small parts (such as knobs, fasteners, seals, grommets, and small electrical parts) that would not significantly contribute to the propagation of fire, all materials used must be self-extinguishing. One means for showing compliance with this requirement is contained in Federal Aviation Regulations (FAR) Part 25, Appendix F.

(4) Operation of Controls. Controls intended for use during flight shall be designed to minimize errors, and when operated in all possible combinations and sequences, shall not result in a condition whose presence or continuation would be detrimental to the continued performance of the equipment.

(5) Accessibility of Controls. Controls that are not normally adjusted in flight shall not be readily accessible to the operator.

(6) Interfaces. The interfaces with other aircraft equipment must be designed such that normal or abnormal windshear warning and escape guidance equipment operation shall not adversely affect the operation of other equipment.

(7) Compatibility of Components. If a system component is individually acceptable but requires calibration adjustments or matching to other components in the aircraft for proper operation, it shall be identified in a manner that will ensure performance to the requirements specified in this TSO.

(8) Interchangeability. System components which are identified with the same manufactured part number shall be completely interchangeable.

(9) Control/Display Capability. A suitable interface shall be provided to allow data input, data output, and control of equipment operation. The control/display shall be operable by one person with the use of only one hand.

(10) Control/Display Readability. The equipment shall be designed so that all displays and controls shall be readable under all cockpit ambient light conditions ranging from total darkness to reflected sunlight and arranged to facilitate equipment usage. Limitations on equipment installations to ensure display readability should be included in the installation instructions.

(11) Effects of Test. The design of the equipment shall be such that the application of the specified test procedures shall not produce a condition detrimental to the performance of the equipment except as specifically allowed.

(12) Equipment Computational Response Time. The equipment shall employ suitable update rates for computation and display of detection and guidance information.

(13) Supplemental Heating or Cooling. If supplemental heating or cooling is required by system components to ensure that the requirements of this TSO are met, they shall be specified by the equipment manufacturer in the installation instructions.

(14) Self-Test Capability. The equipment shall employ a self-test capability to verify proper system operation.

(i) Any manually initiated self-test mode of operation shall automatically return the system to the normal operating mode upon completion of a successful test.

(ii) Any automatically activated self-test feature must annunciate this mode of operation to the pilot if this feature activates annunciation lights, aural messages, or displaces the guidance commands in any way.

(iii) Conduct of the system self-test feature must not adversely affect the performance of operation of other aircraft systems.

(iv) Failure of the system to successfully pass the self-test shall be annunciated.

(15) Independence of Warning and Escape Guidance Functions. Irrespective of whether the warning and escape guidance functions are in a combined system or are separate systems, they should be sufficiently independent such that a failure of either system does not necessarily preclude or inhibit the presentation of information from the other. A warning system failure shall not result in ambiguous or erroneous guidance system mode annunciation.

(16) System Reliability.

(i) The probability of a false warning being generated within the windshear warning system or the windshear warning and escape guidance system shall be 1×10^{-4} or less per flight hour.

(ii) The probability of an unannunciated failure of the windshear warning system or the windshear warning and escape guidance system shall be 1×10^{-5} or less per flight hour (1×10^{-3} or less per flight hour for systems installed in out-of-production aircraft as defined in FAR 121.358).

c. Equipment Functional Requirements - Standard Conditions. The equipment shall meet the following functional requirements.

(1) Mode Annunciation. The windshear escape guidance display mode of operation shall be annunciated to the pilot upon escape guidance activation during a windshear encounter and upon reversion to a different flight guidance mode.

(2) Malfunction/Failure Indications. The equipment shall indicate:

- (i) Inadequate or absence of primary power.
- (ii) Equipment failures.
- (iii) Inadequate or invalid warning or guidance displays or output signals.
- (iv) Inadequate or invalid sensor signals or sources.

These malfunction/failure indications shall occur independently of any operator action. The lack of adequate warning displays, escape guidance information, or sensor signals or sources shall be annunciated when compliance with the requirements of this TSO cannot be assured.

(3) Windshear Caution Alert. If the equipment includes a windshear caution alert:

(i) It shall provide an annunciation of increasing performance shear (updraft, increasing headwind, or decreasing tailwind) in accordance with the shear intensity curve shown in figure 1.

(ii) This caution alert shall display or provide an appropriate output for display of an amber caution annunciation dedicated for this purpose. An aural alert may be provided as an option. The caution display (or output) should remain until the threshold windshear condition no longer exists (not less than a minimum of 3 seconds) or a windshear warning alert occurs.

(iii) Gust conditions shall not cause a nuisance caution alert. Turbulence shall not cause more than one nuisance caution alert per 250 hours (or 3,000 flight cycles based on 1 hour/flight cycle) of system operation.

(4) Windshear Warning Alert.

(i) A windshear warning alert shall provide an annunciation of decreasing performance shear (downdraft, decreasing headwind, or increasing tailwind) with a magnitude equal or greater than that shown in the shear intensity curve shown in figure 1.

(ii) This warning alert shall display or provide an appropriate output for display of a red warning annunciation labeled "windshear" dedicated for this purpose. The visual alert should remain at least until the threshold windshear condition no longer exists or a minimum of 3 seconds, whichever is greater. An aural alert shall be provided that annunciates "windshear" for three aural cycles. The aural alert need not be repeated for subsequent windshear warning alerts within the same mode of operation.

(iii) Gust conditions shall not cause a nuisance warning alert. Turbulence shall not cause more than one nuisance warning alert per 250 hours (or 3,000 flight cycles based on 1 hour/flight) of system operation.

(5) Operating Altitude Range. The system shall be designed to function from at least 50 feet above ground level (AGL) to at least 1000 feet AGL.

(6) Windshear Escape Guidance. Flight guidance algorithms shall incorporate the following design considerations:

(i) At the point of system warning threshold, the available energy of the airplane must be properly managed through a representative number of windfield conditions. These conditions must take into account significant shear components in both the horizontal and vertical axes, individually and in combination.

(ii) The flight path guidance commands must be suitable to the dynamic response of aircraft of the type on which the system is intended for installation.

(iii) If the magnitude of the shear components are such as to overcome the performance capability of the airplane, guidance commands must be such that ground impact will occur in the absence of ability to produce additional lift, absence of excessive kinetic energy, and without putting the aircraft into a stalled condition.

(iv) Flight guidance command information shall be provided for presentation on the primary flight display/attitude direction indicator (PFD/ADI) and any available Head Up Display (HUD).

(v) Flight guidance displays which command flight path and pitch attitude should be limited to an angle-of-attack equivalent to onset of stall warning or maximum pitch command of 27°, whichever is less.

(vi) Flight guidance commands and any auto recovery mode (if included) may be automatically activated concurrent with or after the windshear warning alert occurs or may be manually selected. If manual selection is utilized, it shall only be via the takeoff-go

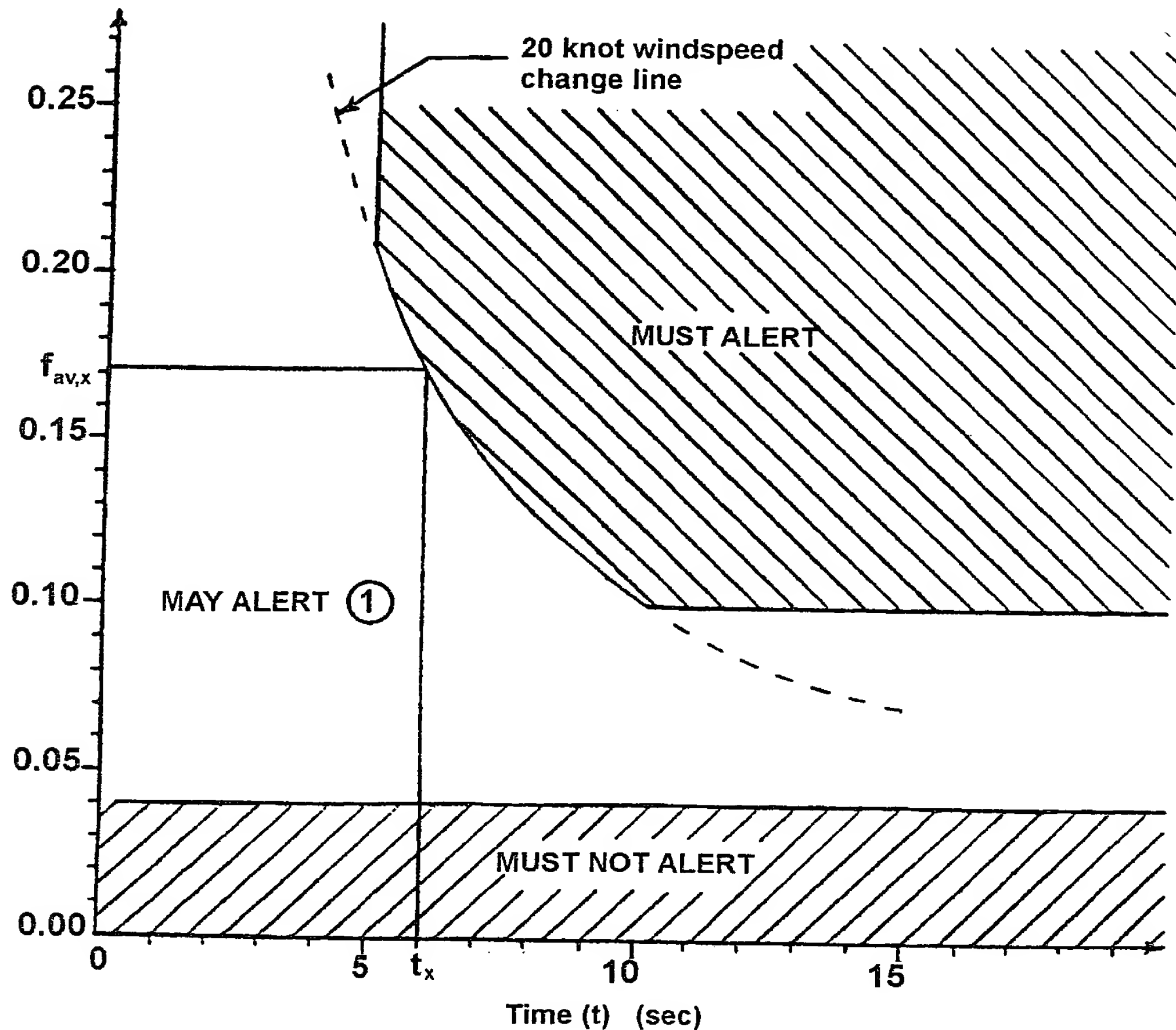
around (TOGA) switch or equivalent means (i.e., a function of throttle position, other engine parameters, etc.).

(vii) Manual deselection of windshear flight guidance and any auto recovery mode (if included) shall be possible by means other than the TOGA switches.

(viii) Systems incorporating automatic reversion of flight guidance commands from windshear escape guidance to another flight guidance mode should provide a smooth transition between modes. Flight guidance commands shall not be removed from the flight guidance display until either manually deselected or until the aircraft, following exit of the warning conditions, has maintained a positive rate of climb and speed above $1.3 V_{s1}$ for at least 30 seconds.

FIGURE 1

SHEAR INTENSITY CURVE



$f_{av,x}$ = average shear intensity to cause a warning at time t_x (resulting in a 20 knot windspeed change, bounded as shown; applies to horizontal, vertical, and combination shear intensities)

$$= \frac{\int_0^{t_x} f(t) dt}{t_x} \text{ whereby } f(t) = \text{instantaneous shear intensity at time } t$$

- ① A nuisance warning test utilizing the Dryden turbulence model and discrete gust model are conducted independently from alert threshold tests to verify the acceptability of potential nuisance warnings due to turbulence or gusts.

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d. Equipment Performance - Environmental Conditions. The environmental tests and performance requirements described in this subsection are intended to provide a laboratory means of determining the overall performance characteristics of the equipment under conditions representative of those that may be encountered in actual operations. Some of the environmental tests contained in this subsection need not be performed unless the manufacturer wishes to qualify the equipment for that particular environmental condition. These tests are identified by the phrase "When Required." If the manufacturer wishes to qualify the equipment to these additional environmental conditions, then these "When Required" tests shall be performed.

Unless otherwise specified, the test procedures applicable to a determination of equipment performance under environmental test conditions are set forth in RTCA Document DO-160B, "Environmental Conditions and Test Procedures for Airborne Equipment." Performance tests which must be made after subjection to test environments may be conducted after exposure to several environmental conditions.

(1) Temperature and Altitude Tests (DO-160B, Section 4.0). RTCA Document DO-160B contains several temperature and altitude test procedures which are specified according to the category for which the equipment will be used. These categories are included in paragraph 4.2 of DO-160B. The following subsections contain the applicable test conditions specified in Section 4.0 of DO-160B.

(i) Low Operating Temperature Test. The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraph 4.5.1, and the following requirements of this standard shall be met:

- (a) Section (c)(1) - Mode Annunciation
- (b) Section (c)(2) - Malfunction/Failure Indications
- (c) Section (c)(3) - Windshear Caution Alert
- (d) Section (c)(4) - Windshear Warning Alert
- (e) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(ii) High Short-Time Operating Temperature Test. The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraph 4.5.2, and the following requirements of this standard shall be met:

- (a) Section (c)(1) - Mode Annunciation
- (b) Section (c)(2) - Malfunction/Failure Indications
- (c) Section (c)(3) - Windshear Caution Alert
- (d) Section (c)(4) - Windshear Warning Alert
- (e) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(iii) High Operating Temperature Test. The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraph 4.5.3, and the following requirements of this standard shall be met:

- (a) Section (c)(1) - Mode Annunciation
- (b) Section (c)(2) - Malfunction/Failure Indications
- (c) Section (c)(3) - Windshear Caution Alert
- (d) Section (c)(4) - Windshear Warning Alert
- (e) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(iv) In-Flight Loss of Cooling Test (When Required). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraph 4.5.4, and the following requirements of this standard shall be met:

- (a) Section (c)(1) - Mode Annunciation
- (b) Section (c)(2) - Malfunction/Failure Indications
- (c) Section (c)(3) - Windshear Caution Alert
- (d) Section (c)(4) - Windshear Warning Alert
- (e) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(v) Altitude Test. The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraph 4.6.1, and the following requirements of this standard shall be met:

- (a) Section (c)(1) - Mode Annunciation
- (b) Section (c)(2) - Malfunction/Failure Indications
- (c) Section (c)(3) - Windshear Caution Alert
- (d) Section (c)(4) - Windshear Warning Alert
- (e) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(vi) Decompression Test (When Required). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraph 4.6.2, and the following requirements of this standard shall be met:

- (a) Section (c)(1) - Mode Annunciation
- (b) Section (c)(2) - Malfunction/Failure Indications
- (c) Section (c)(3) - Windshear Caution Alert
- (d) Section (c)(4) - Windshear Warning Alert

(e) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(vii) Overpressure Test (When Required). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraph 4.6.3, and the following requirements of this standard shall be met:

- (a) Section (c)(1) - Mode Annunciation
- (b) Section (c)(2) - Malfunction/Failure Indications
- (c) Section (c)(3) - Windshear Caution Alert
- (d) Section (c)(4) - Windshear Warning Alert
- (e) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(2) Temperature Variation Test (DO-160B, Section 5.0). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, Section 5.0, and the following requirements of this standard shall be met:

- (i) Section (c)(1) - Mode Annunciation
- (ii) Section (c)(2) - Malfunction/Failure Indications
- (iii) Section (c)(3) - Windshear Caution Alert
- (iv) Section (c)(4) - Windshear Warning Alert
- (v) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(3) Humidity Test (DO-160B, Section 6.0). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, Section 6.0, and the following requirements of this standard shall be met:

- (i) Section (c)(1) - Mode Annunciation
- (ii) Section (c)(2) - Malfunction/Failure Indications
- (iii) Section (c)(3) - Windshear Caution Alert
- (iv) Section (c)(4) - Windshear Warning Alert
- (v) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(4) Shock tests (DO-160B, Section 7.0).

(i) Operational Shocks. The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraph 7.2, and the following requirements of this standard shall be met:

- (a) Section (c)(1) - Mode Annunciation
- (b) Section (c)(2) - Malfunction/Failure Indications
- (c) Section (c)(3) - Windshear Caution Alert
- (d) Section (c)(4) - Windshear Warning Alert
- (e) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(ii) Crash Safety Shocks. The application of the crash safety shock tests may result in damage to the equipment under test. Therefore, this test may be conducted after the other tests have been completed. In this case, section (b)(11), "Effects of Test," of this standard does not apply. The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraph 7.3, and shall meet the requirements specified therein.

(5) Vibration Test (DO-160B, Section 8.0). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160, Section 8.0, and the following requirements of this standard shall be met:

- (i) Section (c)(1) - Mode Annunciation
- (ii) Section (c)(2) - Malfunction/Failure Indications
- (iii) Section (c)(3) - Windshear Caution Alert
- (iv) Section (c)(4) - Windshear Warning Alert
- (v) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(6) Explosion Proofness Test (DO-160B, Section 9.0) (When Required). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, Section 9.0. During these tests, the equipment shall not cause detonation of the explosive mixture within the test chamber.

(7) Waterproofness Tests (DO-160B, Section 10.0).

(i) Drip Proof Test (When Required). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraph 10.3.1, and the following requirements of this standard shall be met:

- (a) Section (c)(1) - Mode Annunciation
- (b) Section (c)(2) - Malfunction/Failure Indications

- (c) Section (c)(3) - Windshear Caution Alert
- (d) Section (c)(4) - Windshear Warning Alert
- (e) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(ii) Spray Proof Test (When Required). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraph 10.3.2, and the following requirements of this standard shall be met:

NOTE: This test shall be conducted with the spray directed perpendicular to the most vulnerable area(s) as determined by the equipment manufacturer.

- (a) Section (c)(1) - Mode Annunciation
- (b) Section (c)(2) - Malfunction/Failure Indications
- (c) Section (c)(3) - Windshear Caution Alert
- (d) Section (c)(4) - Windshear Warning Alert
- (e) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(iii) Continuous Stream Proof Test (When Required). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraph 10.3.3, and the following requirements of this standard shall be met:

- (a) Section (c)(1) - Mode Annunciation
- (b) Section (c)(2) - Malfunction/Failure Indications
- (c) Section (c)(3) - Windshear Caution Alert
- (d) Section (c)(4) - Windshear Warning Alert
- (e) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(8) Fluids Susceptibility Tests (DO-160B, Section 11.0).

(i) Spray Test (When Required). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraph 11.4.1, and the following requirements of this standard shall be met:

At the end of the 24-hour exposure period, the equipment shall operate at a level of performance that indicates that no significant failures of components or circuitry have occurred. Following the two-hour operational period at ambient temperature, after the 160-hour exposure period at elevated temperature, the following requirements of this standard shall be met:

- (a) Section (c)(1) - Mode Annunciation
- (b) Section (c)(2) - Malfunction/Failure Indications
- (c) Section (c)(3) - Windshear Caution Alert
- (d) Section (c)(4) - Windshear Warning Alert
- (e) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(ii) Immersion Test (When Required). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraph 11.4.2, and the following requirements of this standard shall be met:

At the end of the 24-hour immersion period specified in DO-160B, paragraph 11.4.2, the equipment shall operate at a level of performance that indicates that no significant failures of components or circuitry have occurred. Following the two-hour operational period at ambient temperature, after the 160-hour exposure period at elevated temperature, the following requirements of this standard shall be met:

- (a) Section (c)(1) - Mode Annunciation
- (b) Section (c)(2) - Malfunction/Failure Indications
- (c) Section (c)(3) - Windshear Caution Alert
- (d) Section (c)(4) - Windshear Warning Alert
- (e) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(9) Sand and Dust Test (DO-160B, Section 12.0) (When Required). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, Section 12.0, and the following requirements of this standard shall be met:

- (i) Section (c)(1) - Mode Annunciation
- (ii) Section (c)(2) - Malfunction/Failure Indications
- (iii) Section (c)(3) - Windshear Caution Alert
- (iv) Section (c)(4) - Windshear Warning Alert
- (v) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(10) Fungus Resistance Test (DO-160B, Section 13.0) (When Required). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, Section 13.0, and the following requirements of this standard shall be met:

- (i) Section (c)(1) - Mode Annunciation
- (ii) Section (c)(2) - Malfunction/Failure Indications

- (iii) Section (c)(3) - Windshear Caution Alert
- (iv) Section (c)(4) - Windshear Warning Alert
- (v) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(11) Salt Spray Test (DO-160B, Section 14.0) (When Required). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, Section 14.0, and the following requirements of this standard shall be met:

- (i) Section (c)(1) - Mode Annunciation
- (ii) Section (c)(2) - Malfunction/Failure Indications
- (iii) Section (c)(3) - Windshear Caution Alert
- (iv) Section (c)(4) - Windshear Warning Alert
- (v) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(12) Magnetic Effect Test (DO-160B, Section 15.0). The equipment shall be subject to the test conditions as specified in RTCA Document DO-160B, Section 15.0, and the equipment shall meet the requirements of the appropriate instrument or equipment class specified therein.

(13) Power Input Tests (DO-160B, Section 16.0).

(i) Normal Operating Conditions. The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraphs 16.5.1 and 16.5.2, as appropriate, and the following requirements of this standard shall be met:

- (a) Section (c)(1) - Mode Annunciation
- (b) Section (c)(2) - Malfunction/Failure Indications
- (c) Section (c)(3) - Windshear Caution Alert
- (d) Section (c)(4) - Windshear Warning Alert
- (e) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(ii) Abnormal Operating Conditions. The application of the low voltage conditions (DC) (Category B equipment) test may result in damage to the equipment under test. Therefore, this test may be conducted after the other tests have been completed. Section (b)(11), "Effects of Test," does not apply. The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraphs 16.5.3 and 16.5.4, as appropriate, and the following requirements of this standard shall be met:

- (a) Section (c)(1) - Mode Annunciation
- (b) Section (c)(2) - Malfunction/Failure Indications
- (c) Section (c)(3) - Windshear Caution Alert
- (d) Section (c)(4) - Windshear Warning Alert
- (e) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(14) Voltage Spike Conducted Test (DO-160B, Section 17.0).

(i) Category A Requirements (If Applicable). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraph 17.3, and the following requirements of this standard shall be met:

- (a) Section (c)(1) - Mode Annunciation
- (b) Section (c)(2) - Malfunction/Failure Indications
- (c) Section (c)(3) - Windshear Caution Alert
- (d) Section (c)(4) - Windshear Warning Alert
- (e) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(ii) Category B Requirements (If Applicable). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, paragraphs 17.4.1 and 17.4.2, and the following requirements of this standard shall be met:

- (a) Section (c)(1) - Mode Annunciation
- (b) Section (c)(2) - Malfunction/Failure Indications
- (c) Section (c)(3) - Windshear Caution Alert
- (d) Section (c)(4) - Windshear Warning Alert
- (e) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(15) Audio Frequency Conducted Susceptibility Test (DO-160B, Section 18.0).

The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, Section 18.0, and the following requirements of this standard shall be met:

- (i) Section (c)(1) - Mode Annunciation
- (ii) Section (c)(2) - Malfunction/Failure Indications
- (iii) Section (c)(3) - Windshear Caution Alert
- (iv) Section (c)(4) - Windshear Warning Alert
- (v) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(16) Induced Signal Susceptibility Test (DO-160B, Section 19.0). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, Section 19.0, and the following requirements of this standard shall be met:

- (i) Section (c)(1) - Mode Annunciation
- (ii) Section (c)(2) - Malfunction/Failure Indications
- (iii) Section (c)(3) - Windshear Caution Alert
- (iv) Section (c)(4) - Windshear Warning Alert
- (v) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(17) Radio Frequency Susceptibility Test (Radiated and Conducted) (DO-160B, Section 20.0). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, Section 20.0, and the following requirements of this standard shall be met:

- (i) Section (c)(1) - Mode Annunciation
- (ii) Section (c)(2) - Malfunction/Failure Indications
- (iii) Section (c)(3) - Windshear Caution Alert
- (iv) Section (c)(4) - Windshear Warning Alert
- (v) Section (c)(6) - Windshear Escape Guidance

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

(18) Emission of Radio Frequency Energy Test (DO-160B, Section 21.0). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, Section 21.0, and the requirements specified therein shall be met.

(19) Lighting Induced Transient Susceptibility (DO-160B, Section 22.0). The equipment shall be subjected to the test conditions as specified in RTCA Document DO-160B, Section 22.0, and the requirements specified therein shall be met:

Additionally, all system controls, displays, inputs, and outputs shall perform their intended functions.

e. Equipment Test Procedures.

(1) Definitions of Terms and conditions of Tests. The following definitions of terms and conditions of tests are applicable to the equipment tests specified herein:

(i) Power Input Voltage. Unless otherwise specified, all tests shall be conducted with the power input voltage adjusted to design voltage ± 2 percent. The input voltage shall be measured at the input terminals of the equipment under test.

(ii) Power Input Frequency.

(a) In the case of equipment designed for operation from an AC power source of essentially constant frequency (e.g., 400 Hz), the input frequency shall be adjusted to design frequency ± 2 percent.

(b) In the case of equipment designed for operation from an AC power source of variable frequency (e.g., 300 to 1000 Hz), unless otherwise specified, test shall be conducted with the input frequency adjusted to within 5 percent of a selected frequency and within the range for which the equipment is designed.

(iii) Windfield Models. Unless otherwise specified, the windfield models used for tests shall be those specified in appendix 1 of this TSO.

(iv) Adjustment of Equipment. The circuits of the equipment under test shall be aligned and adjusted in accordance with the manufacturer's recommended practices prior to the application of the specified tests.

(v) Test Instrument Precautions. Due precautions shall be taken during the conduct of the tests to prevent the introduction of errors resulting from the connection of voltmeters, oscilloscopes, and other test instruments across the input and output impedances of the equipment under test.

(vi) Ambient Conditions. Unless otherwise specified, all tests shall be conducted under conditions of ambient room temperature, pressure, and humidity. However, the room temperature shall be not lower than 10° C.

(vii) Warm-up Period. Unless otherwise specified, all tests shall be conducted after the manufacturer's specified warm-up period.

(viii) Connected Loads. Unless otherwise specified, all tests shall be performed with the equipment connected to loads which have the impedance values for which it is designed.

(2) Test Procedures. The equipment shall be tested in all modes of operation that allow different combinations of sensor inputs to show that it meets both functional and accuracy criteria.

Dynamic testing provides quantitative data regarding windshear warning and escape guidance equipment performance using a simplified simulation of flight conditions. This testing, when properly performed and documented, may serve to minimize the flight test requirements.

It shall be the responsibility of the equipment manufacturer to determine that the sensor inputs, when presented to the windshear warning and escape guidance equipment, will produce performance commensurate with the requirements of this standard. Additional sensor inputs may be optionally provided to enhance equipment capability and/or performance.

The equipment required to perform these tests shall be defined by the equipment manufacturer as a function of the specific sensor configuration of his equipment. Since these tests may be accomplished more than one way, alternative test equipment setups may be used where equivalent test function can be accomplished. Combinations of tests may be used wherever appropriate.

The test equipment signal sources shall provide the appropriate signal format for input to the specific system under test without contributing to the error values being measured. Tests need only be done once unless otherwise indicated.

The scenarios established for testing windshear warning and escape guidance systems represent realistic operating environments to properly evaluate such systems. The windfield models contained in appendix 1 of this TSO should be used to evaluate the performance of the windshear warning and escape guidance system. The manufacturer may propose different windfield models provided it is shown that they represent conditions at least as severe as those contained in this TSO.

(3) Test Setup. Simulator tests shall be used to demonstrate the performance capability of the windshear warning and escape guidance equipment. A suitable equipment interface shall be provided for recording relevant parameters necessary to evaluate the particular system under test. The aircraft simulator shall be capable of appropriate dynamic modeling of a representative aircraft and of the windfield and turbulence conditions contained in appendices 1 and 2 of this TSO or other windfield/turbulence models found acceptable by the Administrator.

(4) Functional Performance (paragraphs (c)(1) through (c)(6)). Each of the functional capabilities identified in paragraphs (c)(1) through (c)(6) shall be demonstrated with the windshear warning and escape guidance equipment powered. These capabilities shall be evaluated either by inspection or in conjunction with the tests described in paragraphs (e)(5) through (e)(11).

(5) Mode Annunciation (paragraph (c)(1)). With the equipment operating, verify the windshear escape guidance display mode of operation is annunciated to the pilot upon escape guidance activation and upon reversion to a different flight guidance mode.

(6) Malfunction/Failure Indications (paragraph (c)(2)). Configure the equipment for simulation tests as defined in paragraph (e)(3).

(i) With the system active (within the operating altitude range) and inactive (outside the operating altitude range), remove one at a time each required electrical power input to the equipment. There shall be a failure indication by the equipment of each simulated failure condition.

(ii) With the system active (within the operating altitude range) and inactive (outside the operating altitude range), cause each sensor or other signal input to become inadequate or invalid. There shall be a failure indication by the equipment of each simulated failure condition.

(7) Windshear Caution Alert (paragraph (c)(3)). For equipment incorporating a windshear caution alert function, accomplish the following tests:

(i) Configure the equipment for simulation test as defined in paragraph (e)(3). Subject the equipment to acceleration waveform values meeting the following conditions (reference figure 2). The system shall generate an appropriate caution alert (or no alert) within the time intervals specified when subjected to the following average shear intensity ($f_{av,x}$) values:

$f_{av,x}$ (1)	Time of Exposure (t) (sec)	Result
0.02	20	no alert
0.04	20	no alert
0.105	10	alert within 10 sec
$1.049/t$	t	alert within t sec (2)
0.21	5	alert within 5 sec
$=0.270$	5	alert within 5 sec

Notes: (1) The average shear intensity which must result in a caution alert after a time t_x or less meets the definition of $f_{av,x}$ in figure 1. The maximum instantaneous shear intensity of the test waveform is restricted to 0.075 or 100 percent of $f_{av,x}$ above the average shear value $f_{av,x}$, whichever is less. The minimum instantaneous shear intensity of the test waveform is zero. Test waveform rise and fall rates shall be limited to a maximum of 0.1 per second. The shear intensity before time 0 is zero for a sufficiently long time to allow the system to settle to stable conditions.

(2) $t = 6, 7, 8, 9$

The test conditions specified above shall be repeated 5 times. A different waveform for $f_{av,x}$ will be utilized for each of the 5 runs. An appropriate alert (or no alert) must be generated for each test condition.

Verify the system displays or provides an appropriate output for display of an amber caution annunciation dedicated for this purpose. Verify the visual caution display (or output) remains at least until the threshold windshear condition no longer exists or a minimum of 3 seconds (whichever is greater), or until a windshear warning occurs.

(ii) Subject the equipment to windspeeds defined by the Dryden turbulence model contained in appendix 2. The system shall be exposed to these conditions for a minimum of 50 hours (or 600 flight cycles) at each altitude specified in appendix 2 for a minimum total test duration of 250 hours (or 3,000 flight cycles based on 1 hour/flight cycle). No more than one nuisance caution shall be generated during this test.

(iii) Subject the equipment to windspeeds defined by the discrete gust rejection model contained in appendix 2. No alert shall be generated as a result of this test.

(8) Windshear Warning Alert (paragraph (c)(4)).

(i) Configure the equipment for simulation tests as defined in paragraph (e)(3). Subject the equipment to acceleration waveform values meeting the following conditions (reference figure 2). The system shall generate an appropriate warning alert (or no alert) within the time intervals specified when subjected to the following average shear intensity ($f_{av,x}$) values:

$f_{av,x}$ (1)	Time of Exposure (t) (sec)	Result
0.02	20	no alert
0.04	20	no alert
0.105	10	alert within 10 sec
$1.049/t$	t	alert within t sec (2)
0.21	5	alert within 5 sec
≥ 0.270	5	alert within 5 sec

Notes: (1) The average shear intensity which must result in a warning alert after a time t_x or less meets the definition of $f_{av,x}$ in figure 1. The maximum instantaneous shear intensity of the test waveform is restricted to 0.075 or 100 percent of $f_{av,x}$ above the average shear value $f_{av,x}$, whichever is less. The minimum instantaneous shear intensity of the test waveform is zero. Test waveform rise and fall rates shall be limited to a maximum of 0.1 per second. The shear intensity before time 0 is zero for a sufficiently long time to allow the system to settle to stable conditions.

(2) $t = 6, 7, 8, 9$

The test conditions specified above shall be repeated 5 times. A different waveform for $f_{av,x}$ will be utilized for each of the 5 runs. An appropriate alert (or no alert) must be generated for each test condition.

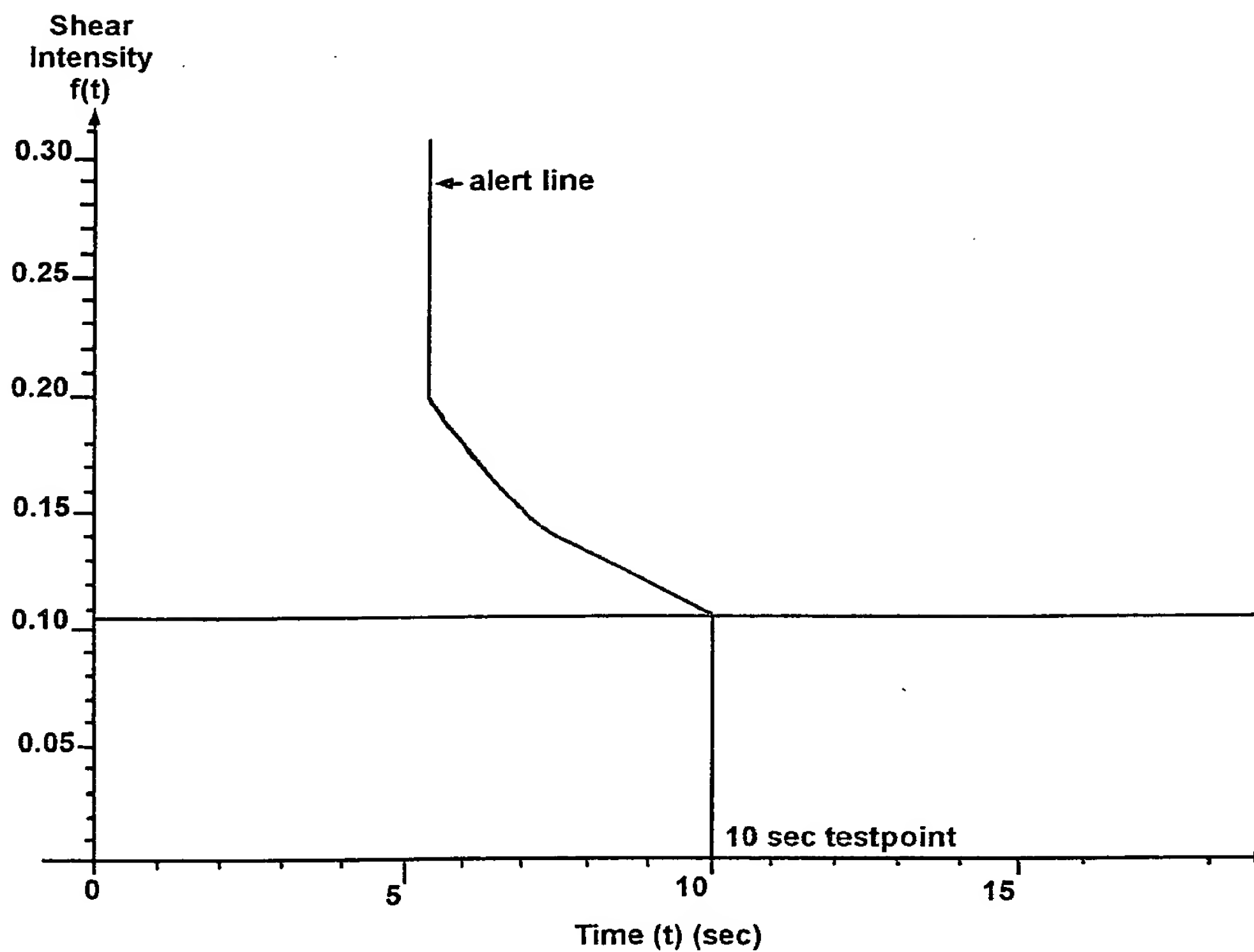
Verify the system displays or provides an appropriate output for display of a red warning annunciation labeled "windshear" dedicated for this purpose. Verify the visual warning display (or output) remains until the threshold windshear condition no longer exists or a minimum of 3 seconds, whichever is greater. Verify an aural alert is provided that annunciates "windshear" for three aural cycles.

(ii) Subject the equipment to windspeeds defined by the Dryden turbulence model contained in appendix 2. The system shall be exposed to these conditions for a minimum of 50 hours (or 600 flight cycles) at each altitude specified in appendix 2 for a minimum total test duration of 250 hours (or 3,000 flight cycles based on 1 hour/flight cycle). No more than one nuisance warning shall be generated during this test.

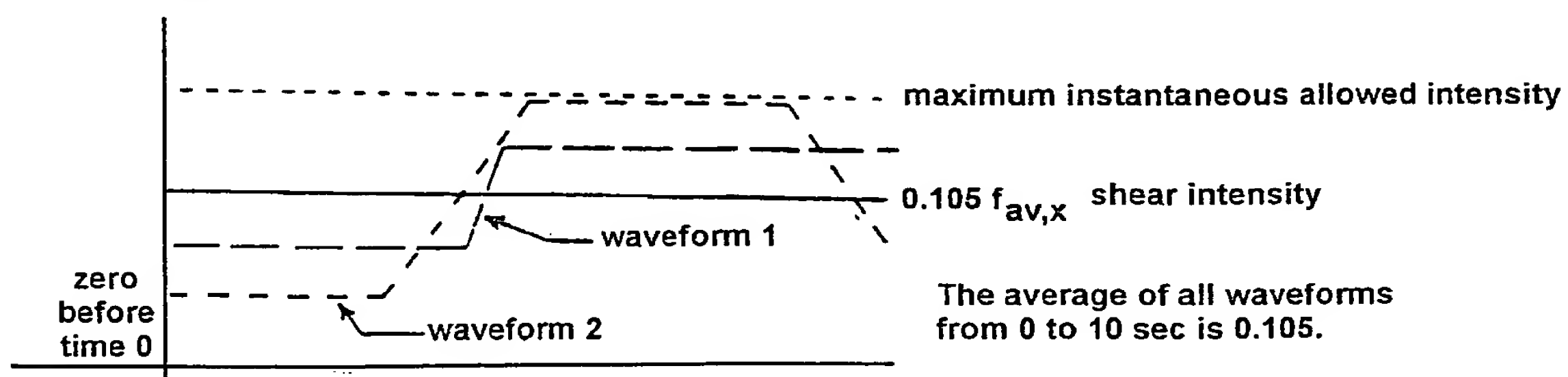
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FIGURE 2
WINDSHEAR ALERT TEST



Sample waveforms for 10 sec test point



(iii) Subject the equipment to windspeeds defined by the discrete gust rejection model contained in appendix 2. No alert shall be generated as a result of this test.

(9) Operating Altitude Range (paragraph (c)(5)). Configure the equipment for simulation tests as defined in paragraph (e)(3). Simulate a takeoff to an altitude of at least 1500 feet AGL. Verify the windshear warning and escape guidance system is operational from at least 50 feet AGL to at least 1000 feet AGL. Simulate an approach to landing from 1500 feet AGL to touchdown. Verify the windshear warning and escape guidance system is operational from at least 1000 feet AGL to at least 50 feet AGL.

(10) Windshear Escape Guidance (paragraph (c)(6)). Configure the equipment for simulation tests as defined in paragraph (e)(3). Subject the equipment to each of the windfield conditions contained in appendix 1 for each operating mode (takeoff, approach, landing, etc.) available. Each test condition shall be repeated 5 times. Recovery actions for the fixed pitch method comparison shall be initiated immediately upon entering the shear condition.

(i) Verify the flight path guidance commands manage the available energy of the aircraft to achieve the desired trajectory through the shear encounter. These tests shall be performed with vertical only, horizontal only, and combination vertical and horizontal shear conditions.

(a) For the takeoff case, verify the flight guidance commands produce a trajectory that provides a resultant flight path at least as good (when considered over the entire spectrum of test cases) as that obtained by establishing a 15° pitch attitude (at an approximate rate of 1.5° per second) until onset of stall warning and then reducing pitch attitude to remain at the onset of stall warning until exiting the shear condition. Evidence of a significant decrement (considered over the entire spectrum of test cases) below the flight path provided by the fixed pitch method that results from use of the guidance commands provided by the system must be adequately substantiated.

(b) For the approach/landing case, verify the flight guidance commands produce a trajectory that provides a resultant flight path at least as good (when considered over the entire spectrum of test cases) as that obtained by establishing maximum available thrust and a 15° pitch attitude (at an approximate rate of 1.5° per second) until onset of stall warning and then reducing pitch attitude to remain at the onset of stall warning until exiting the shear condition. Evidence of a significant decrement (considered over the entire spectrum of test cases) below the flight path provided by the fixed pitch method that results from use of the guidance commands provided by the system must be adequately substantiated.

(c) For shear conditions exceeding the available performance capability of the aircraft, verify the flight guidance commands result in ground impact in the absence of ability to produce additional lift, absence of excessive kinetic energy, and without putting the aircraft into a stalled condition.

(ii) Verify the flight guidance command outputs are capable of display on associated flight displays. Interface specifications shall be verified and determined to be appropriate for the systems identified in the equipment installation instructions.

(iii) Verify that pitch attitude commands do not result in an angle-of-attack exceeding the onset of stall warning or a maximum pitch command of 27° , whichever is less.

(iv) For systems incorporating manual activation of recovery flight guidance commands, verify the system is activated only by the TOGA switches (or equivalent means). For systems providing automatic activation of recovery guidance, verify the system is activated concurrent with the windshear warning alert.

(v) Verify that windshear recovery guidance commands and any automatic recovery mode can be deselected by a means other than the TOGA switches.

(vi) For systems incorporating automatic reversion of flight guidance commands from windshear escape guidance to another flight guidance mode, verify that the transition between flight guidance modes provides smooth guidance information.

(vii) Verify flight guidance commands are not removed from the flight guidance display until either manually deselected or until the aircraft, following exit of the warning conditions, has maintained a positive rate of climb and speed above $1.3 V_{s1}$ for at least 30 seconds.

f. Computer Software. If the equipment design implementation includes a digital computer, the computer software must be verified and validated in an acceptable manner. One acceptable means of compliance for the verification and validation of the computer software is outlined in RTCA Document No. DO-178A, "Software Considerations in Airborne Systems and Equipment Certification," dated March 1985. For those applicants who elect to use RTCA Document No. DO-178A to demonstrate compliance for the verification and validation of the computer software, the following requirements must be met:

(1) RTCA Document No. DO-178A defines three levels of software; Level 1, 2, and 3. The applicant must declare the level (or levels) to which the computer software has been verified and validated. If the equipment incorporates more than one software level, appropriate partitioning of different software levels is required. The software for windshear warning and escape guidance functions must be verified and validated to at least Level 2. An installation safety analysis for a particular aircraft installation should be accomplished to determine if software must be verified and validated to the more stringent Level 1 requirements.

(2) The applicant must submit a software verification and validation plan for review and approval.

NOTE: The FAA strongly recommends early discussion and agreement between the applicant and the FAA on the applicant's proposed software verification and validation plan, and the applicant's proposed software level or levels.

g. Marking. In addition to the marking specified in Federal Aviation Regulations (FAR) Section 21.607(d), the following information shall be legibly and permanently marked on the major equipment components:

(1) Each separate component of equipment that is manufactured under this TSO must be permanently and legibly marked with at least the name of the manufacturer and the TSO number.

(2) With regard to FAR Section 21.607(d)(2), the part number is to include hardware and software identification, or a separate part number may be utilized for hardware and software. Either approach must include a means for showing the modification status.

(3) The level(s) to which the computer software has been verified and validated.

h Data Requirements.

(1) In addition to FAR section 21.605, the manufacturer must furnish the Manager, Aircraft Certification Office (ACO), Federal Aviation Administration, having purview of the manufacturer's facilities, one copy each of the following technical data:

(i) Operating instructions.

(ii) Equipment limitations.

(iii) Installation procedures and limitations.

(iv) Schematic drawings as applicable to the installation procedures.

(v) Wiring diagrams as applicable to the installation procedures.

(vi) Specifications.

(vii) List of major components (by part number) that make up the equipment system complying with the standards prescribed in this TSO.

(viii) An environmental qualifications form as described in RTCA Document DO-160B for each component of the system.

(ix) Manufacturer's TSO qualification test report.

(x) Nameplate drawing.

(xi) The appropriate documentation as defined in RTCA Document DO-178A, or equivalent, necessary to support the verification and validation of the computer software to Level 1 or 2. If the software is verified and validated to more than one level, the appropriate documentation for all such levels must be submitted.

(2) In addition to those data requirements that are to be furnished directly to the FAA, each manufacturer must have available for review by the Manager of the ACO having purview of the manufacturer's facilities, the following technical data:

(i) A drawing list, enumerating all of the drawings and processes that are necessary to define the article's design.

(ii) The functional test specification to be used to test each production article to ensure compliance with this TSO.

(iii) Equipment calibration procedures.

(iv) Corrective maintenance procedures (within 12 months after TSO authorization).

(v) Schematic drawings.

(vi) Wiring diagrams.

(vii) Documentation to support the computer software verification and validation plan for Level 1 or 2 software.

(viii) The appropriate documentation as defined in RTCA Document DO-178A, or equivalent, necessary to support the verification and validation of the computer software to Level 1 or 2. If the software is verified and validated to more than one level, the appropriate documentation for all such levels must be available for review.

(ix) The results of the environmental qualification tests conducted in accordance with RTCA Document DO-160B.

i. Data to be Furnished with Manufactured Units. One copy of the data and information specified in paragraphs i(l)(i) through (viii) of this TSO, and instructions for periodic maintenance and calibration which are necessary for continued airworthiness must go to each person receiving for use one or more articles manufactured under this TSO. In addition, a note with the following statement must be included:

“The conditions and tests required for TSO approval of this article are minimum performance standards. It is the responsibility of those desiring to install this article either on or within a specific type of class of aircraft to determine that the aircraft installation conditions are within the TSO standards. The article may be installed only if further evaluation by the applicant documents an acceptable installation and is approved by the Administrator.”

j. Availability of Reference Documents.

(1) Copies of RTCA Documents Nos. DO-160B and DO-178A may be purchased from the RTCA, Inc., Washington, DC 20005.

(2) Federal Aviation Regulations Part 21, Subpart O; Advisory Circular (AC) 25-12, "Airworthiness Criteria for the Approval of Airborne Windshear Warning Systems in Transport Category Airplanes"; AC 20-110C, "Index of Aviation Technical Standard Orders"; and AC 120-41 "Criteria for Operational Approval of Airborne Windshear Alerting and Flight Guidance Systems"; may be reviewed at FAA Headquarters in the Aircraft Certification Service, Aircraft Engineering Division (AIR-100), and at all regional ACO's.

/S/ John K. McGrath
Manger, Aircraft Engineering
Division, AIR-100